

MEASUREMENT OF X-RAY EMISSION WAVE-LENGTHS BY  
MEANS OF THE RULED GRATING

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A DISSERTATION  
SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS  
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN THE  
UNIVERSITY OF MICHIGAN

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# The Measurement of X-Ray Emission Wave-Lengths by Means of the Ruled Grating

By R. B. WITMER

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With a plane ruled grating, measurements have been made of the emission wave-lengths in the *L* series for the elements Va (23) to Zn (30) and in the *K* series for the elements C (6) to Si (14). With the exception of the *K* $\alpha$  lines of carbon, fluorine and oxygen, the method of the ruled grating yields a longer wave-length in every case than that found for the corresponding lines by the crystal method. The Moseley diagrams representing the observed results are found to be smooth curves. The possible variation of apparent wave-length with a variation in the grazing angle of incidence has been investigated. For angles such that the diffracted lines were not too diffuse, the computed wave-lengths were independent of the incident angle.

## INTRODUCTION

SEVERAL investigations have now been carried out to determine the wave-lengths of x-ray spectral lines by means of ruled gratings. In certain of these investigations measurements have been made relative to some particular emission line whose wave-length assumed as a standard has been measured by the Bragg method with a crystal. In other experiments<sup>1,2,3,4</sup> the wave-lengths have been determined directly from the measurable constants of the apparatus. The results for the wave-lengths so far obtained by this latter method are found in every case to be greater than the corresponding values found by means of the usual crystal method. Disagreement exists only in the magnitude of the discrepancy.

The apparent existence of this difference raises a very important question. If the measurements by means of crystals are correct then there is some defect in applying to the ruled grating in the case of x-rays the same theory that is found satisfactory in the visible and the ultraviolet spectral regions. If the measurements by means of the ruled grating are correct then there is something in error in calculations involving the Bragg law, other than the effect due to the ordinary refraction of x-rays in the crystal, which can be accounted for. If this error exists in the lattice constant *d* then it reflects upon our knowledge of certain other more fundamental constants, namely

<sup>1</sup> E. Bäcklin, *Dissertation*, Upsala, 1928.

<sup>2</sup> J. A. Bearden, *Proc. Nat. Acad. Sci.* **15**, 528 (1929); *Phys. Rev.* **37**, 1210 (1931).

<sup>3</sup> J. M. Cork, *Phys. Rev.* **35**, 1456 (1930).

<sup>4</sup> C. E. Howe, *Phys. Rev.* **35**, 717 (1930).

the number of particles per gram molecule  $N$  or the charge of the electron  $e$  from which  $N$  is derived.

The answer to this question can be given only after the accumulation of extensive data obtained with the utmost care. This must include measurements of the indices of refraction of certain crystals for various wave-lengths as well as the determination of the wave-lengths themselves by the different methods. Toward this end the present investigation was undertaken to determine as accurately as possible the wave-lengths of the emission lines in the  $K$  series for elements Si(14) to C(6) and in the  $L$  series for elements Zn(30) to Va(23).

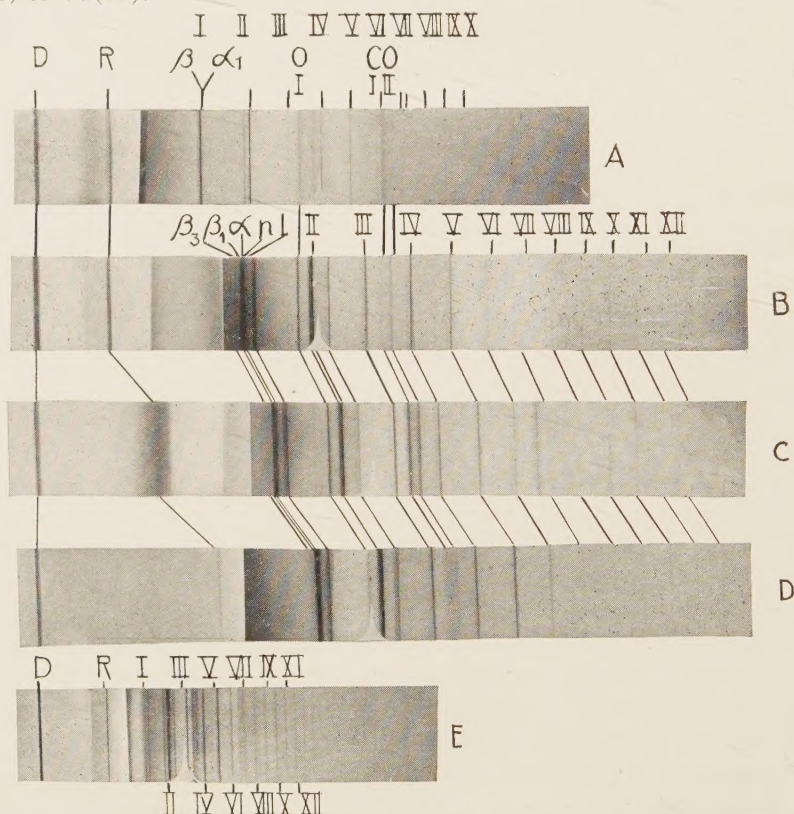


Fig. 1. Spectrograms with ruled grating. (A)  $K$  lines of silicon,  $\theta = 30' 26''$ ; (B, C and D)  $L$  lines of copper for  $\theta = 30' 26''$ ,  $\theta = 51' 20''$  and  $\theta = 1^\circ 16' 5''$ , respectively; (E) same as (D) with photographic plate close to grating.

#### APPARATUS

The apparatus employed is similar to that used previously by one of us<sup>3</sup> in the determination of the wave-lengths of the  $L$  series lines of molybdenum. It is believed that this arrangement which makes use of outside spectral orders and employs a grating which when once properly adjusted is left absolutely fixed during a series of exposures is least subject to errors of manipulation.



The following changes in the apparatus were made. The glass grating employed in this investigation was ruled in the laboratory of Professor M. Siegbahn and obtained through his kindness. The active surface was 3 mm wide and the lines were 2 cm long. Nominally having 600 lines per mm a calibration with known wave-lengths in the arc spectrum of mercury gave for the distance  $d$  between lines ( $d = 0.00166309$  mm). The glass surface between the rulings and the outside of the plate was etched down on one side so that the direct beam going to the photographic plate was limited on one side by the edge of the ruled surface. The collimating system consisted of parallel slits 0.05 mm wide spaced 20 cm apart. A water-cooled x-ray tube of metal was used in place of the glass tube. A very fine knife edge was placed parallel and close to the rulings of the grating at the center. This reduced materially the stray radiation and general blackening on the photographic plate.

The procedure in taking exposures with the photographic plate at different distances from the grating was followed as previously described. For any particular substance on the target at least five exposures were taken with the photographic plate in a position  $a$  close to the grating and then in the position  $d$  at a maximum distance from the grating. Reproductions of some typical spectrograms are given in Fig. 1. At least six and sometimes as many as twelve measurable orders were obtained on each photogram.

### RESULTS

A summary of the results obtained for the wave-lengths in the  $K$  series for the elements investigated is given in Table I. Similarly in Table II are given the values obtained for the wave-lengths in the  $L$  series. Along with the results of this investigation are shown the corresponding values from experiments using the crystal method as well as those of other experimenters

TABLE I. *Summary of wave-lengths in the K series.*

| Element     | Crystal | Söderman <sup>5</sup> | Thibaud <sup>6</sup> | Witmer and Cork |
|-------------|---------|-----------------------|----------------------|-----------------|
| Si $\beta$  | 6.754   | —                     | —                    | 6.764           |
| Si $\alpha$ | 7.110   | —                     | —                    | 7.121           |
| Al $\beta$  | 7.965   | —                     | —                    | 7.967           |
| Al $\alpha$ | 8.320   | —                     | —                    | 8.334           |
| Mg $\beta$  | 9.539   | —                     | —                    | 9.558           |
| Mg $\alpha$ | 9.869   | —                     | —                    | 9.898           |
| Na $\alpha$ | 11.885  | 11.88                 | —                    | 11.910          |
| F $\alpha$  | 18.37   | 18.275                | —                    | 18.354          |
| O $\alpha$  | 23.73   | 23.567                | 23.80                | 23.644          |
| C $\alpha$  | 45.50   | 44.54                 | 44.90                | 44.448          |

with the ruled grating. In the  $L$  series for the elements mentioned here, measurements by the crystal method have been carried out by Siegbahn and Thoriaeus<sup>7,8</sup> and by Karlsson.<sup>9</sup> The values from these investigations are

<sup>5</sup> M. Söderman, *Phil. Mag.* **10**, 600 (1930).

<sup>6</sup> J. Thibaud, *J. Opt. Soc. Am.* **17**, 145 (1928).

<sup>7</sup> M. Siegbahn and R. Thoriaeus, *Ark. Mat. Astr. O. Fys.* **18**, 24 (1924).

<sup>8</sup> R. Thoriaeus, *Phil. Mag.* **1**, 312 (1926); **2**, 1007 (1926).



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